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Negotiation Process for Green Reverse Supply Chain Coordination: Case Study in Pharmaceutical Industry

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Abstract.. This paper investigates the pharmaceutical reverse supply chain. For this industry, the reverse supply chain is usually not owned by a single company. A decentralized negotiation process is thus presented in order to coordinate the collection of unwanted medications at customer zones. Using a Lagrangian relaxation method, the model is solved for a real generic pharmaceutical company. Coordination efforts are required from the supply chain entities, facing environmental regulations, to collect and recycle unwanted medications. Therefore, a bonus sharing technique is also proposed based on each entity's investment in the coordination process. Some numerical results are presented and discussed for two case studies. It shows that up to 28% more products could be collected if companies coordinate their operations efficiently. Besides, future insights on the same network are highlighted.

Keywords. Pharmaceutical reverse supply chain, coordination, bonus sharing, linear programming.

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1. Introduction

Alterations in the state of the environment, which result from industrial manufacturing activities, caused a quantum leap for the supply chain management (SCM) and business practices. Customer pressure and environmental legislations also raise the complexity for performance measurement of reverse supply chains (RSC). Up till now, most of RSC actions are market-driven; i.e. companies take the initiative to reduce costs by reusing the waste of unsold parts. However, in Europe some actions are legislation-driven to fulfill the obligatory regulations of collecting specific amounts of end-of-life products (return stream) in order to avoid penalties forced by governments [1].

A good example is the pharmaceutical industry. In fact, this industrial field has developed at a very fast rate in the last decades. It is a rapidly growing market due to the increased rate of modern century diseases and the raised number of old-age nations. Likewise, the presence of pharmaceutical products as trace pollutants for environment has been firmly established. Knowing the potential severity of using expired or improper drugs, the recovery process of unsold or unwanted medications is essential [2]. A wide range of proactive actions is therefore necessary to reduce or minimize the introduction of pharmaceutical wastes to the environment. Pharmaceutical RSC is considered as one of the complicated supply chains because of the restricted percentages of chemicals in medications and the regulated conditions for distribution and storage. Furthermore, the zero-salvage value of returned medications hinders the development of RSC [3]. In other words, it differs from other RSC, such as electronics industry RSC, where the salvage value of the returned products is significant.

This study focuses on tactical planning in the pharmaceutical RSC. In general, tactical level decisions include many actions, such as collection of waste materials, recycling, long-term RSC chain coordination contract drafting, recovery channels of reverse logistics, and recovery efforts designing [4, 5]. Since pharmaceutical RSC activities fall outside core functions of a company, the majority of the activities are usually handled through third-part logistics (3PL)

providers [6]. Using 3PLs enables companies to focus more on their own core processes and reduce the associated costs. Moreover, 3PL providers usually update their information technology and techniques, which are more flexible than in-source logistics. Despite the aforementioned advantages, some companies might lose control inherent in outsourcing particular functions, due to the limited collaboration between the supply chain entities [7]. For example, in our case, due to the lack of collaboration, a part of unsold/expired medications remain at customer zones.

In reality, supply chains are not typically owned by one company. They consist of facilities that are managed by different companies, like producers, retailers, 3PLs, etc. Hence decision-making system in such supply chains is bound to fail unless a coherent approach of coordination is utilized. Coordination in networks are either a centralized process that has a unique decision maker who possesses all information on the entire network, or a decentralized process that has multiple decision makers [8]. Product recovery problem is complex; i.e. many factors and constraints of information sharing are required for accurate modeling. For example, information are needed about collection volume, frequencies, locations, and cost associated with collection and disposal [9]. In the pharmaceutical industry, paucity of information may be observed as a result of the lack of trust between entities, hence, prohibiting the coordination of the RSC [10]. This paper assumes a decentralized decision making process and proposes a negotiation approach as a coordination mechanism in the RSC described herein.

We propose a coordination model for a real pharmaceutical RSC from the retailer point of view, who represents the producer company, *Generic PharmaX*. In the past, the producer policy did not include collecting the unsold items from outside the country because she believed that medications have a null salvage value. As a result, the company, through her retailer, used to send new items instead and ask the retailer to either burn or bury the unwanted drugs. This type of disposal harms the environment and the groundwater. As a result, the environmental reputation of the company was affected. For example, in one of

her European markets, the medications were thrown in the sea and polluted the water. Afterwards, the government in that market banned the producer from selling her medications. Moreover, the government established legislations for bringing back every unwanted item to the country of origin. This added more transportation costs and other subsidiary problems for the company.

Therefore, the producer now needs to find ways to recycle these items or dispose them safely instead of burning them and damaging the environment. Moreover, the environmental concerns in the origin country of the company are increasing, so greening the supply chain puts a step ahead making the company a pioneer in the national as well as the international markets. Under the new business context, the producer has to handle her returned medications in compliance with the legislations in different markets. Otherwise, she has to pay different penalties to governments for each unit of uncollected medications. Indeed, the producer pays the retailer for collecting the unwanted or unused medications at customer zones (i.e. hospitals and pharmacies). The retailer is thus responsible for negotiation with 3PLs over quantities that must be collected, i.e. the retailer controls the reverse supply chain communication, as shown in figure (1). The retailer next pays fees, i.e. *collecting fees* to 3PLs, for collecting the discarded medications at customer zones, as well as sorting and delivering to sinks of the network. The sinks are governmental safe disposal and recycling facilities (figure (1)).

Currently, the coordination between the retailer and 3PL companies is insufficient. In other words, about 20% to 40% of the available unwanted medications remain uncollected. As a consequence, the producer has not only to pay penalties but she also loses some markets. Furthermore, she would be in an unenviable reputation among competitors. Therefore, new strategies have to be implemented to ensure supply chain coordination and reduce the environmental impacts.

Because the company used to pay penalties to governments for uncollected medications at customer zones, we suggest her to share that amount with RSC entities instead and green her reputation. In other words, to minimize the fees

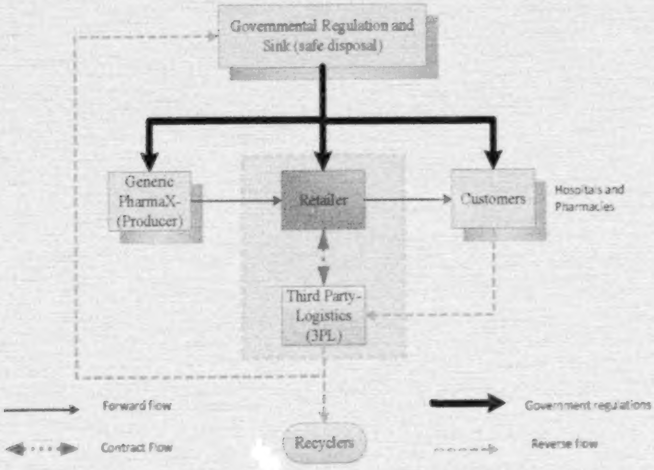

Figure 1: The Pharmaceutical Reverse Supply Chain

and penalties that she pays to governments, we suggest the producer to offer the retailer an extra fixed amount, i.e. a *bonus*, on top of the regular collecting fees. The bonus is paid if, and only if, all unwanted products at customer zones are collected. We believe that this extra income for RSC entities will motivate those who are eager to collaborate and participate in greening the network. Therefore, the retailer objective is to ensure that all unwanted products are collected. As a result, the retailer has to pay adequate collecting fees for 3PL companies to collect more products. Moreover, the retailer needs to share the predictable bonus with the 3PLs to guarantee a complete collection of products at customer zones. The reason is that the 3PLs objective is to maximize the individual profit from collecting products and from recycling some of returned products.

This paper, as a first research on the pharmaceutical RSC coordination, contributes to the available literature by modeling this RSC in order to meet environmental legislations and reduce the amount of wastes. It is a challenging RSC because the recovery products have almost no economical values to recy-

clers or to producers. Using data from a real case study, a single period tactical planning model is developed. The producer has to fulfill the regulations and improve her green image among competitors and customers. The RSC model considered herein consists of one retailer, four third-party logistics, and four recyclers. A coordination approach based on a negotiation mechanism is applied to handle the communication within the network. With the aid of Lagrangian relaxation, four sub-problems are solved for small-case and large-case problems. In addition, an appropriate method to share the network gain from an improved coordination is suggested, which shares the savings based on each entity's effort. Moreover, the effect of the proposed coordination method on the performance of the RSC is analyzed.

The reminder of this paper is organized as follows. A literature review regarding RSC and coordination mechanisms is first proposed. A brief description of the case study context and the pharmaceutical RSC tactical planning model are next given in section 3. Also, section 3 covers the proposed negotiation methodology to solve the model and the suggested profit sharing technique. Some numerical results and discussions for the real case study are given in section 4. Finally, some concluding remarks are provided in section 5.

2. Literature Review

There is a growing stream of literature on product recovery and RSC. However, the available literature on the pharmaceutical RSC is still limited and the existence research is scant. Detailed reviews on RSC models can be found in [11, 12]. Blackburn et al. [13] highlighted the growing interest in RSC in today's business. As the large body of literature on RSC planning shows, mixed integer programming (MIP) models are the common models for the quantitative planning of many case studies [14, 15]. However, most of the discussed models are for single facility problems. Very recently, Brandenburg et al. [16] presented a holistic review of the available literature prior to 2014 on quantitative models for SCM including RSC. Lambert et al. [17] proposed a conceptual framework

for RSC including generic process decisions, economic aspects, and performance measures with respect to the tactical level decisions. Sbihi and Eglese [9] focused on combinatorial optimization problems in a network with waste management and reverse logistics. Hoshino et al. [18] constructed a linear goal programming model to maximize the total profit and recycling rate for recycle-oriented manufacturing systems. Likewise, Karakayalı et al. [19] investigated the pricing and recovery planning problem in a single-period setting.

Regarding the literature on pharmaceutical RSC, few works can be found. Shih and Lin [20] presented a multiple criteria optimization approach to minimize the cost for collection system planning for medical waste. Recently, Kumar et al. [6] proposed a framework to state each party's responsibility in the pharmaceutical RSCs. They suggested the usage of consistent information systems and carriers to streamline the supply chain. The absence of collaboration in their model with 3PLs draws into question the ability of the model in tracking the products. In addition, the study ignored the criterion of sharing any possible benefits of using this technology as well as sharing the implementation cost among the entities. Lately, Xie and Breen [3] designed a green pharmaceutical supply chain model to reduce preventable pharmaceutical waste and to dispose inevitable waste. The study revealed that the RSC is not really utilized in the pharmaceutical industry since returned medications cannot be reused or resold. Hence, with the new environmental regulations, supplier collaboration and customer cooperation were addressed to boost the RSC. However, the cost of recycling or collecting returned/unwanted medications was not considered.

Collaboration in supply chains can be defined as a long-term relationships among entities through sharing resources and knowledge. Camarinha-Motas [21] presented a holistic overview on the key concepts, classifications, and some applications related to collaboration. The relevant literature on coordination and collaboration in RSC is very recent because of the complexity in these chains. Examples on the intricacies are anti-trust problems, lost of control, and the inherent uncertainty, such as local policies, quality of returned products, etc [22]. To reduce uncertainty, efforts are needed to increase the coordination in the

RSC by changing the relationship between cost-value-profit equations [23]. One of the coordination mechanisms that we focus on, herein, is negotiation processes. However, most of the available literature, concerning this coordination mechanism, is on the forward supply chain.

Jung et al. [24] proposed a negotiation process for a distributor and a manufacturer to find a feasible plan for supply quantities from the manufacturer to the distributor with a minimum amount of information revelation to partners. They stated that complete information sharing is essential to solve centralized planning model. Dudek ans Stadtler [25, 26] suggested using some incentives to boost the negotiation process. Li [27] examined the incentives in a two-level supply chain (one manufacturer and many retailers). His study expressed that the direct and leakage effects of information sharing discourage retailers from collaboration. Hence, Cachon [28] suggested the use of contracts based on five types of incentives to facilitate the coordination of partners' activities in the forward supply chain. One of the incentives can be the price charged by the supplier to the customer, which is known as wholesale-price. The second is the use of buyback policy of returning all unsold items. When the retailer has a portion of the revenue as an incentive, they will go for long-term collaboration, as they will be part of the profit cycle. Another incentive is to give some flexibility to the supplier of the demand over the minimum quantity to provide. Finally, reducing the cost by increasing the quantity will encourage the buyer to have more. Recently, Lehoux et al. [29] studied a two-echelon supply chain in the pulp and paper industry. They explained that using different coordination mechanisms provided higher gains for network entities. Moreover, Kusukawa and Arizono [30] suggested a profit sharing mechanism for a forward supply chain.

In reality, as mentioned earlier, the information access between RSC entities is very limited. Therefore, Walther et al. [31] developed a decentralized negotiation model to enable allocating product recovery tasks for recycling companies. Lagrangian relaxation optimization method was used to solve the model. The method was applied to an electronic case study in Europe. It can be said that,

up till recently, Walther et al. [31] research is the only mathematical model available in the literature for coordination in RSC. The recovery activities in the electronic industry have a value-added to the supply chain income. However, in the pharmaceutical industry, the salvage value of the medication recovery is almost negligible. Hence, coordination approach in the latter is more challenging. Furthermore, the profit sharing among the network entities was not studied in [31]. Since the negotiation requires an invested effort from RSC entities, this should be rewarded by sharing the benefits among the entities. In our contribution, we present a negotiation process as well as a technique to share the savings based on invested efforts for each entity.

3. The Model

3.1. The Producer: Generic PharmaX

In our case study, the producer is a leading multinational pharmaceutical company that was founded in the Middle East for more than 35 years. The Company focuses on developing a branded pharmaceuticals business across the Middle East, North Africa, Europe, and in the United States. Figure (2) shows the main processes and activities in the producer company. The activities of *Generic PharmaX* start from the sales and marketing unit, which works to get contracts and find markets for their products. Based on sales amount, the demand is planned through communication with the finance department to check the available cash. The forecasting department will improve the plan of demand and issue purchasing orders to buy raw materials and equipment. Meanwhile, supply planning department organizes the capacity of machines to reduce the setup time. Once everything is organized, the production process starts.

The company manufactures two main forms of drugs: liquid form and solid form. Legislations and regulation need to be obeyed, especially with toxic materials. Through quality assurance activity, the drugs are tested before going to the packaging unit and later to warehouses. Finally, the drugs are shipped to

retailers in many countries through land freights, airplanes, or ships. Usually,

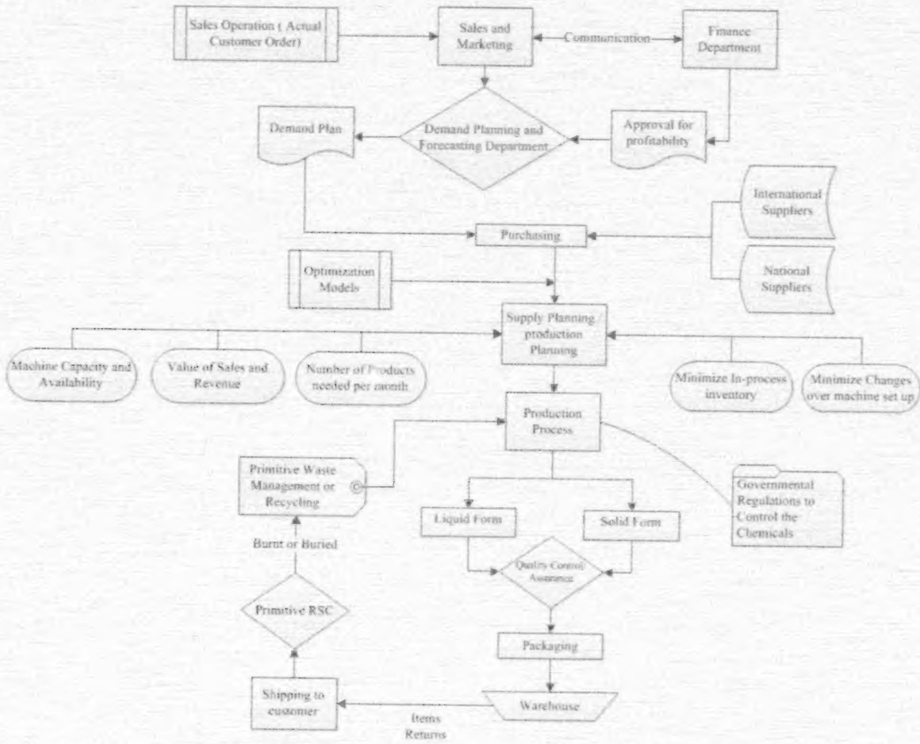

Figure 2: Generic PharmaX Process Mapping

retailers are responsible for distributing the medications to customers in the forward supply chain. Moreover, the retailers are responsible for the collection of unwanted medications in RSC. As mentioned before, the recovery activities in the company are very primitive

3.2. RSC Single Period Tactical Planning Problem in the Case Study

As estated earlier, the producer of medications, Generic PharmaX, is facing governmental legislations to green her supply chain activities. Moreover, she used to pay penalties to governments for uncollected medications at customer

zones. Therefore, in order to help the producer improving her RSC, we propose her a coordination model to guarantee the collection of all available amounts of medications at customer zones. However, because the medication recovery process involves a certain logistics cost but a small salvage value, the coordination model in such supply chains is bound to fail unless a motivation technique is utilized to encourage RSC entities to collaborate. This mechanism is shown in figure (3). The figure depicts the RSC entities of the proposed coordination model and illustrates the interaction among them.

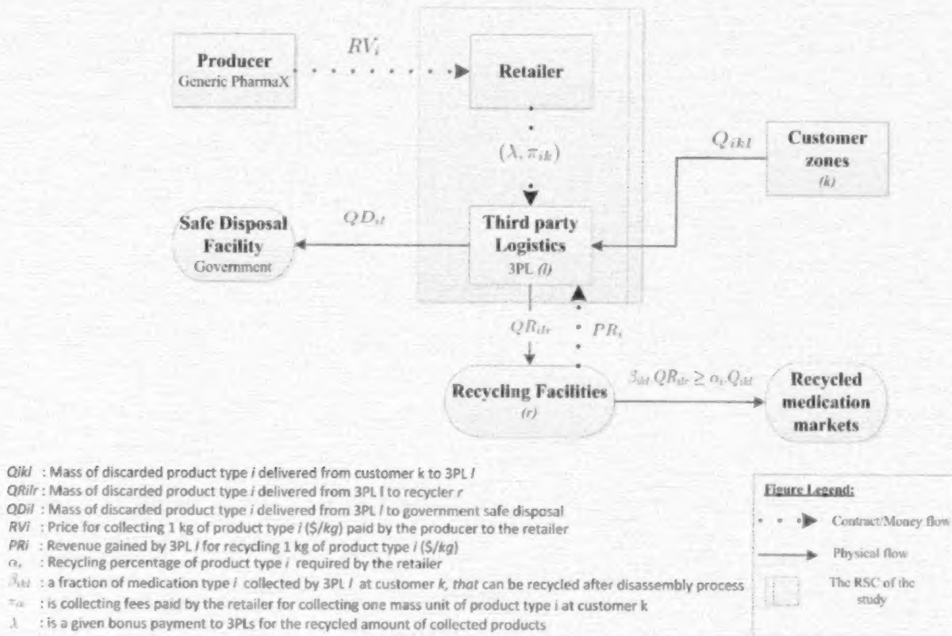

Figure 3: The Pharmaceutical RSC of the Proposed Coordination Model

Since the RSC activities fall outside core functions of the producer, the majority of those activities are outsourced. The producer pays a retailer for collecting medications at customer zones. More precisely, she pays the retailer a price of RV_i for collecting 1 kg of product type i. The retailer, as a representative

of the producer in the RSC, controls the RSC activities. However, the retailer is not qualified to handle the returns by himself. Hence, he contracts with one or more third-party logistics (3PL) companies to pick up and recycle the leftover medications at customer zones. With the goal of greening the RSC, the retailer, as the representative of the producer in the RSC, sets a target for recycling certain percentages (α_i) of the total medication collected by 3PL companies at customer zones. 3PL companies reach the target through sending the collected mass to recyclers, which are assumed to be under their control. Furthermore, in order to avoid penalties due to the uncollected medications at customer zones, the retailer needs to make sure all leftovers are collected by 3PL companies. Hence, the retailer proposes contract offers to 3PL companies, involving two parameters, then checks the collected and recycled amounts. The first parameter stands for collecting one unit of product type i at customer zone k (collecting fees π_{ik}). On the other hand, the recycling process is infrequent in the pharmaceutical industry because it has almost no economical values to 3PL companies. Therefore, in order to motivate the 3PL companies to recycle some medications, a second parameter is offered by the retailer for each unit recycled from the collected medications (bonus payment λ). In the light of the contract offers, the role of 3PL companies is to pick up the available medications at customer zones (Q_{ikl}). Furthermore, 3PL companies have to deliver the medications, after sorting and separating them, to the RSC sinks; encompassing a government safe disposal and different recycling facilities.

As aforementioned, the retailer requests a certain percentage from each product to be recycled (α_i). Therefore, the 3PL companies have to meet the recycling mass required by the retailer ($\alpha_i.Q_{ikl}$). Then, 3PL companies send the mass (QR_{ilr}) to recycling facilities as shown in figure (3). In the recycling facilities, the medications are disassembled to packaging, containers, etc. The recyclable fraction of a medication type i at recycling facilities is represented as β_{ikl}. The recyclable amounts of the delivered medications at recycling facilities should at least reach the target imposed by the retailer ($\beta_{ikl}.QR_{ilr} \geq \alpha_i.Q_{ikl}$). By the same token, the recycled masses at recycling facilities are fractions of the col-

lected amounts at customer zones ($\beta_{ikl}.QR_{ilr}$). The recycling facilities sell the recycled mass in recycled medication markets, at a price of PR_i. For example, an ethanol of 98% purity can be extracted from medications and sold to paints factories, where it can be used as a solvent in paints. At last, hazardous and non-recyclable medications have to be sent to the governmental safe disposal facilities to be disposed in a secure area (QD_{il}). Based on this context, a mathematical model for the case study can be formulated as shown in the following sections.

3.2.1. Centralized Model

Currently, the retailer contracts with many 3PLs to collect the unwanted products based on fixed non-negotiable prices (collecting fees) as follows. The retailer has the information about the available amounts at each customer zone, i.e. she has the power over other entities. She informs 3PLs with contract parameters (collecting fees and recycling targets) for collecting medications. Then, each 3PL company sends the retailer the amount that they are willing to collect. Each 3PL company's objective is to maximize her profit of collecting with respect to her own collecting cost, transportation cost, and collection and recycling capacities. In contrary, the retailer's goal is to fulfill the recovery targets.

A comprehensive solution for the whole RSC could be obtained if the retailer has all the required information for each 3PL company. She could manage and assign each 3PL company an amount to collect in order to ensure a complete collection for the medications. Following is the model in case of full information availability to the retailer, corresponding to RSC depicted in figure (1) and figure (3).

Indices and Sets

i	index of products, $i \in I$
k	index of customers (hospitals and pharmacies), $k \in K$
l	index of 3PL, $l \in L$

r index of recyclers, $r \in R$

Parameters

RV_i Price for collecting 1 kg of product type i ($\$/kg$) paid by the producer to the retailer

PR_i Revenue for recycling 1 kg of product type i ($\$/kg$)

P_i Fees paid to government to dispose 1 kg of product type i ($\$/kg$)

RC_{ir} Recycling cost of product i at recycler r

DC_{il} Cost for collecting and sorting product type i at 3PL l

TC_{ikl} Transportation costs of 1 kg of product type i from customer k to 3PL l

TCR_{ilr} Transportation costs of 1 kg of product type i from 3PL l to recycler r

TD_{il} Transportation costs of 1 kg of product type i from 3PL l to governmental safe disposal

α_i Recycling percentage of product type i

M_{ik} Mass of product type i that has to be collected at customer k

CAP_l Capacity available at 3PL l (\$)

$CAPR_r$ Capacity available at recycler r (\$)

β_{ikl} a fraction of medication type i collected by 3PL l at customer k that can be recycled after disassembly process

Decision Variables

Q_{ikl} Mass of discarded product type i delivered from customer k to 3PL l

QR_{ilr} Mass of discarded product type i delivered from 3PL l to recycler r

QD_{il} Mass of discarded product type i delivered from 3PL l to government safe disposal sink

rec_{rl} Total mass approved to be sent to recycling facility r by 3PL l

RSC centralized model

$$\textbf{Maximize Z} = \sum_{l\in L}\sum_{k\in K}\sum_{i\in I} RV_i.Q_{ikl} + \sum_{l\in L}\sum_{r\in R}\sum_{i\in I} PR_i.QR_{ilr} - \sum_{l\in L}\sum_{i\in I} TD_{il}.QD_{il}$$
$$-\sum_{l\in L}\sum_{k\in K}\sum_{i\in I} TC_{ikl}.Q_{ikl} - \sum_{l\in L}\sum_{r\in R}\sum_{i\in I} TCR_{ilr}.QR_{ilr} - \sum_{l\in L}\sum_{r\in R}\sum_{i\in I} RC_{ir}.QR_{ilr}$$
$$-\sum_{l\in L}\sum_{i\in I} P_i.QD_{il} - \sum_{l\in L}\sum_{k\in K}\sum_{i\in I} DC_{il}.Q_{ikl} \tag{1}$$

s.t.

$$\sum_{k\in K} Q_{ikl} = \sum_{r\in R} QR_{ilr} + QD_{il} \qquad \forall i \in I, \forall l \in L \tag{2}$$

$$\sum_{l\in L}\sum_{i\in I} TCR_{ilr}.QR_{ilr} \leq CAPR_r \qquad \forall r \in R \tag{3}$$

$$\sum_{k\in K}\sum_{i\in I} DC_{il}.Q_{ikl} \leq CAP_l \qquad \forall l \in L \tag{4}$$

$$\sum_{l\in L}\sum_{k\in K}\sum_{i\in I} \alpha_i.Q_{ikl} \leq \sum_{r\in R} rec_{rl} \tag{5}$$

$$\sum_{r\in R} rec_{rl} = \sum_{r\in R}\sum_{i\in I} \beta_{ikl}.QR_{ilr} \qquad \forall l \in L \tag{6}$$

$$M_{ik} = \sum_{l\in L} Q_{ikl} \qquad \forall i \in I, \forall k \in K \tag{7}$$

$$Q_{ikl}, QR_{ilr}, QD_{il}, rec_{rl} \geq 0$$
$$i \in I, k \in K, r \in R, l \in L \tag{8}$$

The objective function (1) maximizes the total profit of the supply chain. This represents the economical balance between the incomes and costs of the whole SC entities. The income is calculated by the summation of 3PLs revenue for collecting medications and the revenue of recycling portion of the collected

amounts at recycling sites. The cost is calculated by the summation of the transportation costs of RSC channels, disposal costs, and recycling costs at customer zones. The model is constrained by conservation of flow through network channels and capacity constraints for recycling facilities and for each 3PL company site. In addition, the masses that have to be sent to each recycling facility are considered, based on the percentage of recycling of that product type. In other words, each product has a possibility to recycle part of it, for example packages, etc. The recycled masses have to meet the recycling target of each product. Moreover, all of unsold products at each customer site have to be collected and moved to 3PL facilities.

The first constraint (2) ensures the conservation of mass flow on the 3PLs node; masses collected from customer k equal to masses sent to recycling plus masses sent to governmental sink. Constraints (3) explains the capacity of the recyclers in dollars as a unit of medication type i delivered from 3PL l to recyclers r multiply by transportation costs of 1 kg of product type i from 3PL l to recyclers r. Constraint (4) is a capacity constraint in dollars for 3PL company and it is calculated by multiplying the cost of 1 kg collected from product type i with the collected masses of that medication type i. Constraint (5) calculates the masses that have to be sent to each recycling facility by multiplying the collected masses of product type i with the percentage of recycling of that product type. Constraint (6) guarantees that the recycled masses at least reach the target of recycling of product type i. Constraint (7) confirms that all of unsold product type i at customer k are collected and moved to 3PL facilities. The last constraints are non-negativity constraints.

However, the 3PLs might not accept the prices and quantities offered by the retailer or would not agree to share their information. It therefore becomes necessary to model the tactical planning problem in a decentralized manner and to use a mechanism in order to coordinate it efficiently.

3.2.2. Coordination Model Based on Negotiation Approach

Solving the centralized model, as mentioned earlier, needs private information sharing between RSC entities. As some examples we can mention the capacity available at 3PLs (CAP_l), transportation cost from 3PLs to recyclers (TCR_{ilr}), transportation cost from 3PLs to safe disposal (TD_{il}), and so on. In fact, RSC entities are not currently willing to share this knowledge with others. Moreover, some constraints are common constraints for all 3PLs, such as collecting all of unwanted medications (constraint (7)). Therefore, a decentralized approach is needed to reflect business reality.

Inspired by [31], a negotiation based coordination approach is suggested to optimize the value of collected quantities and the collecting fees. The retailer leads the negotiation process and offers collecting and recycling fees to 3PLs. The offers and reactions are exchanged until both parties agreed upon certain values of the parameters, as summarized in figure (4).

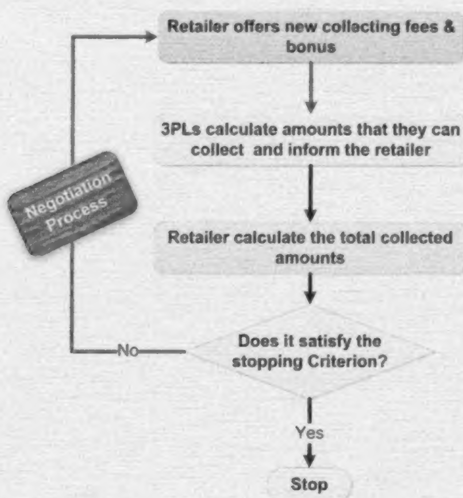

Figure 4: Negotiation Procedure in the Pharmaceutical RSC

Looking at the structure of the centralized model, it can been seen that constraints (5) and (7) are related to the retailer, who tries to ensure the collection and recycling of medications. However, those constraints are dependent

constraints based on private information of 3PLs. In other words, by deleting constraints (5) and (7) from the centralized model, a sub-model for each 3PL company can be obtained. Even so, those deleted constraints have to be satisfied in order to solve the model. Therefore, the retailer proposes contract offers to 3PLs and checks the collected amounts. Two parameters are considered as contract parameters: π_{ik} and λ. π_{ik} is collecting fees paid by the retailer for collecting one mass unit of product type i at customer k. Besides, in order to green the supply chain, λ is a given bonus payment to 3PLs for the recycled amount of collected products. If not all of the medications are collected, the retailer will revise the contract offers (figure (4)).

This negotiation process can be mathematically represented by the aid of Lagrangian relaxation method. Details of Lagrangian relaxation method can be found in [32, 33]. More precisely, the retailer relaxes the common constraints (constraints (5) and (7)) and adds them to the objective function of the model as shown in equation (9). Also, the violation of the constraints is penalized in the objective function by Lagrangian multipliers (the contract parameters). The extra notations used in the negotiation process are shown below.

Coordination model notations

$Z^{LR}(\lambda, \pi_{ik})$ is the objective function of the RSC Lagrangian relaxation model;

$Z^{LR}(\lambda, \pi_{ik})^*$ is the optimal objective function value of the RSC Lagrangian relaxation model;

$Z_l(\lambda, \pi_{ik})$ is the objective function for each 3PL model l;

$Z_l^*(\lambda, \pi_{ik})$ is the optimal objective function value for each 3PL model;

$\sum_{l \in L} Z_l^*(\lambda, \pi_{ik})$ is the summation of optimal objective function values for all 3PL companies.

Lagrangian Relaxation function of the RSC model

$$Z^{LR}(\lambda, \pi_{ik})^* = Maximize\ Z^{LR}(\lambda, \pi_{ik})$$

$$= \sum_{l\in L}\sum_{k\in K}\sum_{i\in I} RV_i.Q_{ikl} + \sum_{l\in L}\sum_{r\in R}\sum_{i\in I} PR_i.QR_{ilr} - \sum_{l\in L}\sum_{i\in I} TD_{il}.QD_{il}$$
$$-\sum_{l\in L}\sum_{k\in K}\sum_{i\in I} TC_{ikl}.Q_{ikl} - \sum_{l\in L}\sum_{r\in R}\sum_{i\in I} TCR_{ilr}.QR_{ilr} - \sum_{l\in L}\sum_{r\in R}\sum_{i\in I} RC_{ir}.QR_{ilr}$$
$$-\sum_{l\in L}\sum_{i\in I} P_i.QD_{il} - \sum_{l\in L}\sum_{k\in K}\sum_{i\in I} DC_{il}.Q_{ikl} - \lambda(\sum_{l\in L} rec_{rl} - \sum_{l\in L}\sum_{k\in K}\sum_{i\in I}\alpha_i.Q_{ikl})$$
$$-\sum_{i\in I}\sum_{k\in K}\pi_{ik}.(M_{ik} - \sum_{l\in L} Q_{ikl}) \tag{9}$$

After some rearrangements for equation (9), we can rewrite the same equation (equation (9)) for the RSC model as shown in equation (10).

$$Z^{LR}(\lambda, \pi_{ik})^* = Maximize \ \sum_{l\in L} Z_l^*(\lambda, \pi_{ik}) - \sum_{i\in I}\sum_{k\in K}\pi_{ik}.M_{ik} \tag{10}$$

From equation (10), a separate model is extracted for each 3PL company with a profit maximization objective function as shown in equation (11) and with respect to constraints (12)-(16). The 3PL model generates an optimal local plan for each 3PL company l with respect to the contract offered by the retailer.

3PL model

$$Z_l^*(\lambda, \pi_{ik}) = Maximize \ \ Z_l(\lambda, \pi_{ik}) = \sum_{k\in K}\sum_{i\in I}((RV_i + \pi_{ik} + \lambda.\alpha_i) - TC_{ikl} - DC_{il})Q_{ikl}$$
$$+\sum_{r\in R}\sum_{i\in I}(PR_i - RC_{ir} - TCR_{ilr})QR_{ilr} - \sum_{i\in I}(TD_{il} + P_i)QD_{il} - \lambda\sum_{r\in R} rec_r \tag{11}$$

s.t.

$$\sum_{k\in K} Q_{ikl} = \sum_{r\in R} QR_{ilr} + QD_{il} \qquad \forall i \in I \tag{12}$$

$$\sum_{i\in I} TCR_{ilr}.QR_{ilr} \leq CAPR_r \qquad \forall r \in R \tag{13}$$

$$\sum_{k\in K}\sum_{i\in I} DC_{il}.Q_{ikl} \leq CAP_l \tag{14}$$

$$\sum_{r\in R} rec_r = \sum_{r\in R}\sum_{i\in I} \beta_{ikl}.QR_{ilr} \qquad \forall r \in R \tag{15}$$

$$Q_{ikl}, QR_{ilr}, QD_{il}, rec_r \geq 0$$
$$i \in I, k \in K, r \in R, l \in L \tag{16}$$

Solving the Lagrangian relaxation model starts with proposing values for λ and π_{ik} by the retailer. Each 3PL company solves the model to find the optimal plans and presents the values to the retailer. Afterwards, the retailer checks the common constraints based on 3PLs' values. If the common constraints are not satisfied, the retailer reviews the values again and iterates over them with 3PLs. As mentioned before, no information is shared between entities. Consequently, a sub-gradient procedure of Lagrangian dual function is used to get a global optimal of this model.

For the Lagrangian relaxation model, $Z^{LR}(\lambda, \pi_{ik})$, let π^t_{ik} be the value of π_{ik} at iteration t and $\sum_{l\in L} Q^t_{ikl}$ be the optimal value of $\sum_{l\in L} Q_{ikl}$ at the same iteration.

$$g^t_{\pi_{ik}} = \sum_{l\in L} Q^t_{ikl} - M_{ik} \tag{17}$$

Equation (17) is the sub-gradient function of the corresponding relaxed constraint (constraint (7)) at π^t_{ik}, i.e. $g^t_{\pi_{ik}}$ represents the violation of the relaxed constraint in iteration t. As long as the relaxed constraint is unsatisfied, the new Lagrangian multiplier (π_{ik}) is calculated as follows:

$$\pi^{t+1}_{ik} = \pi^t_{ik} + \mu_t.g^t_{\pi_{ik}} \tag{18}$$

where μ_t is a positive scalar step size at iteration t and is calculated as $\mu_t = b/t||g||$, b is a scalar quantity and $||g||$ is the Euclidean norm of the sub-gradient. By the same token, let λ^t be the value of the bonus payment (λ) at iteration t, hence

$$g^t_\lambda = \sum_{l\in L}\sum_{k\in K}\sum_{i\in I} \alpha_i.Q^t_{ikl} - \sum_{r\in R} rec^t_{rl} \tag{19}$$

represents the violation of the corresponding relaxed constraint (constraint (5)) at iteration t. As long as the relaxed constraint is unsatisfied, the Lagrangian multiplier is updated as follows:

$$\lambda^{t+1} = max(0, \lambda^t + \mu_t.g_\lambda^t) \tag{20}$$

The process is repeated for a number of iterations until both relaxed constraints are satisfied.

The solution of the sub-model is not necessarily an optimal solution for the centralized network model. Therefore, the solution space of the model needs to be restricted to generate a global feasible solution. We add a new constraint to the sub-model (11)-(16) in order to ensure that the maximum value of the collected product has to be less than or equal to the maximum available medication for each 3PL company. The value of Q_{ikl}^{max} is a fraction of the available masses (equation (21)):

$$Q_{ikl} \leq Q_{ikl}^{max} \quad \forall i, k, l \tag{21}$$

The aforementioned procedure runs until the targeted amounts in constraints (5) and (7) are collected. Based on the assigned values to each 3PL company, the retailer calculates her cost, which is the money paid to each 3PL company and the money paid to the government (for safe disposal and penalty for uncollected masses at customer zones). Also, the 3PLs calculate their cost along with their revenue.

3.3. Sharing the Bonus Between RSC Entities

As mentioned earlier, the retailer is willing to share her bonus, received from the producer, with RSC entities based on their coordination efforts. Motivated by a recent work of [30], the following is a suggested procedure for sharing the bonus between the retailer and 3PLs.

1. Find the difference between the collected amount in the proposed negotiation-based approach with the current collected amounts (based on Generic PharmaX historical data) ($\Delta E = Q_{ikl}^{negotiation-based} - Q_{ikl}^{historical}$).

2. If $\Delta E > 0$, calculate the cost of collecting this difference based on the negotiation-based model for each 3PL company.
3. Calculate the investment rates (N) of the 3PL company in both cases (the case of negotiation-based approach and the current collected amount) as:

$$N_{3PL} = \frac{\text{The cost of collecting } \Delta E}{\text{Total cost of collecting } Q_{ikl}^{negotiation-based}}$$

and for the retailer calculate the ratio as the money paid to 3PLs divided by the money received from the producer:

$$N_{Retailer} = \frac{\pi_{ik}.Q_{ikl} + \lambda.rec}{RV_i.Q_{ikl}}$$

Then, normalize the investment ratios (N^{nor}) as follows:

$$N_{3PL}^{nor} = \frac{N_{3PL}}{N_{3PL} + N_{retailer}} \quad and \quad N_{Retailer}^{nor} = \frac{N_{Retailer}}{N_{3PL} + N_{retailer}}$$

4. Calculate the share of the retailer and 3PL from the bonus (S) as:

$$S_{3PL} = Bonus.N_{3PL}^{nor} \quad and \quad S_{Retailer} = Bonus.N_{Retailer}^{nor}$$

4. Numerical Results and Discussions

Through the communication with the head of Generic PharmaX supply chain department, the required data were obtained from the producer. The data were next refined based on the top markets and medication groups of the company. The four 3PLs were also selected among the largest collectors, where the top four and twenty medications selling amounts were selected for the small and large cases, respectively. The model was solved for small and large cases using Lagrangian relaxation. Results are given for 4 third-party logistics and 4 recyclers. Each 3PL company has different values for transportation and recycling costs, capacities, location, etc. Table 1 shows the capacity for each 3PL company.

The next sections describe the results from the negotiation-based model and the real amounts of the collected medications which have led to some managerial insights. Each entity effort is also rewarded by sharing the bonus of the network. Finally, a validation of the results is presented for the shared amounts between RSC entities and corresponding costs.

Table 1: Third-Party Logistics Capacities ($)

	Large case	Small case
3PL 1	4,700.00	75.00
3PL 2	3,000.00	100.00
3PL 3	4,560.00	78.00
3PL 4	2,850.00	150.00

4.1. Negotiation Model Results

As we mentioned earlier, the main concern in this research is how to coordinate independent RSC players towards a common goal for the network. Negotiation was therefore used as a way to encourage 3PLs to recover as much products as possible while taking into account both retailer and 3PLs constraints. The model was solved by relaxing the two common constraints (Equations (5) and (7)) and penalizing them in the objective function. Using *Cplex*, the model was run for many iterations and evaluated for different values of b. The used values for b were 5, 10, and 30. When all the available amounts (M_{ik}) were collected, we stop running the model. With respect to the step size, small step sizes resulted in smaller optimality gap, i.e. more stable results. The values of collecting fees, π_{ik}, were varied as shown in the second column of Table 2. The actual collecting fees are given in the third column in the same table. The last row in the table corresponds to the price of each mass of unwanted medications that is approved to be recycled. The last four columns in the table represent the Q_{ikl} that has been collected by each 3PL company. Similar table for large scale problem (i.e., twenty products are recovered) is given in Appendix A1.

It can be seen, in table 2, that some of the calculated collecting fees are lower than the actual collecting fees and some are higher. For example in the small case, for product type 3 at customer zone 3, π_{33}, the actual collecting fees is higher than collecting fees in the coordinated model. Since 3PL 2 and 3PL 4 fully utilize their capacities, the assignable amount to 3PL 1 or 3PL 3 cannot be taken by them. Hence, the retailer has to increase the collecting fees up to a certain limit where 3PL 1 and 3PL 3 can collect all jobs allocated to them.

Table 2: Small Case: Collecting Fees ($/kg) for 1 kg of a Product

	Collecting fees	Current collecting fees	3PL 1	3PL 2	3PL 3	3PL 4
π_{11}	0	0.5	3.75	3.75	3.75	3.75
π_{12}	0.224	0.5	9	9	9	9
π_{13}	0.388	0.5	7.5	7.5	7.5	7.5
π_{14}	0.015	0.5	1.25	1.25	1.25	1.25
π_{21}	0.495	0.45	8.75	8.75	8.75	8.75
π_{22}	0.793	0.45	11.36	11.36	11.375	11.375
π_{23}	0.012	0.45	6.38	6.38	6.38	6.375
π_{24}	0.089	0.45	2.5	2.5	2.5	2.5
π_{31}	0.583	3.55	0	4	2.75	4.25
π_{32}	2.718	3.55	4.60	13.75	13.75	22.90
π_{33}	4.340	3.55	21	21	21	21
π_{34}	3.061	3.55	13.75	21.25	0	20
λ	0.306	-	-	-	-	-

On the other hand, 3PL 2 and 3PL 4 gain more from the higher collecting fees. The reason is that 3PL 2 and 3PL 4 could collect the allocated quantities with lower contractual collecting fees, as shown in Table 3.

The profit of each RSC entity is given in the first four rows of Table 3. 3PL 4 has the largest profit for the small case, where for the large case, 3PL 1 has the largest profit. Also, the transfer payment from the retailer to each 3PL is given in rows from 6-9. The total transfer payments are given in row 10. It is calculated by multiplying the collecting fees (π_{ik}) and (λ) with the collected and recycled amounts.

The retailer has to pay an extra $312,675 thousands to ensure that all products at small case are collected. This is calculated by the difference between the actual collecting fees minus the collecting fees in the coordinated model. By the same token, we calculated the value for the large scale as $1,807.34 thousands.

4.2. Results Validation and Bonus Sharing

To understand the effect of different collecting fees on the collected amounts, the model was solved using the actual collecting fees as Lagrangian multipliers in the sub-model (11)-(16). The results show that the current collecting fees leads

Table 3: Profits and Transfer Payments Paid to 3PLs

	Small case	Large case
Profit of 3PL 1(in $1000)	1,796.9	146,179.0
Profit of 3PL 2 (in $1000)	1,705.9	106,507.2
Profit of 3PL 3 (in $1000)	1,478.9	122,533.3
Profit of 3PL 4(in $1000)	1,884.8	111,871.9
Total profits of 3PL companies (in $1000)	6,866.2	487,091.3
Transfer payments from the retailer to 3PL 1 (in $1000)	2,074.2	7,578.6
Transfer payments from the retailer to 3PL 2 (in $1000)	2,065.3	2,625.6
Transfer payments from the retailer to 3PL 3 (in $1000)	1,690.2	4,481.0
Transfer payments from the retailer to 3PL 4 (in $1000)	2,205.1	3,229.8
Total transfer payments	8,034.8	17,915.1
Capacity utilization of 3PL 1 (%)	88	100
Capacity utilization of 3PL 2 (%)	100	78
Capacity utilization of 3PL 3 (%)	86	100
Capacity utilization of 3PL 4 (%)	100	90

to lower collected amounts than the collected amount in the coordinated model. In particular, up to 28% more products are collected for small case and up to 18% in case of large scale problem when the RSC is coordinated, as it can be observed in Table 4. In the small case, based on the governmental penalties for not collecting unwanted medications, the uncollected amounts with the actual collecting fees would cost Generic PharmaX around $2 millions. In the large scale problem, the penalties could be around $93 millions.

Table 4: Total Amounts Collected (kg) with Different Collecting Fees

		Coordinated model	Current situation
Small Case	Total collected amounts	407	294.64
	Total uncollected amounts	0	112.36
Large case	Total collected amounts	24,060	19,768.48
	Total uncollected amounts	0	4,291.51

In table 5, we compare the profit of each entity for the small and the large case regarding the actual collecting fees and the collecting fees in the coordinated

model. For 3PL 2, 3PL 3, and 3PL 4, it can be seen that their profits in the coordinated model are less than their profits in the current model for the small case. As a result, they have to gain some extra bonus in order to be encouraged to collaborate with the retailer and to be compensated for profit lost. However, for the large scale, all of the 3PLs have increased their profits. We therefore investigated the impact of different values of bonus paid by Generic PharmaX to the retailer on the RSC using the procedure mentioned earlier.

Tables 6 and 7 provide the part of the bonus obtained by each 3PL company and by the retailer from different amounts paid by the producer (Generic PharmaX) for collecting the whole amount of unwanted medications at customer zones. The first row of the aforementioned tables provides different amounts of bonus while the rest of the rows provide the bonus shared based on the procedure proposed in section 3.3.

As we can see in table 6, a bonus of \$500 thousands would only be profitable for 3PL 1 since it is the only entity that has a positive profit. However, it is not the case for the rest of RSC entities. Expressly, by looking at table 5, we can see that 3PL 2 will loose about \$260 thousands via a negotiation protocol. By considering a bonus of only \$500 thousands, the part obtained by 3PL 2 would be of \$225 thousands, which is less than the loss by about \$35 thousands. For the \$1,500 thousands bonus scenario, this would be beneficial for 3PL 1 and 3PL 2 but not for the rest of RSC entities. The third scenario of \$2,000 thousands is valuable for all 3PLs but not for the retailer. The sixth scenario is satisfactory for all RSC entities. Henceforth, the offered bonus by Generic PharmaX has to be greater than or equal to \$2,250 thousands to ensure that every RSC entity gains some bonus and that the loss due to accepting the coordinated collecting fees is compensated.

Table 5: Profit Comparison (in \$1,000)

	Coordinated model	Current status	The difference
		Small case	
3PL 1	1,796.89	1,522.54	271.35
3PL 2	1,705.92	1,966.67	-260.75
3PL 3	1,478.9	1,674.12	-195.22
3PL 4	1,884.84	2,176.85	-292.01
Retailer*	-763.087	-450.675	-312.41
		Large case	
3PL 1	146,179	112,011.32	34,167.68
3PL 2	106,507.2	91,973.51	14,533.69
3PL 3	122,533.3	116,231.73	6,301.572
3PL 4	111,871.9	90,980.38	20,891.52
Retailer*	-19,768.5	-17,915.13	-1,853.37

* Since the fees, paid by the producer to the retailer, are constant, they are neglected from the calculations for the retailer.

Table 6: Small Case: Bonus Sharing Between RSC Entities (in \$1,000)

	N	N^{nor}_{3PL}	\$500	\$1,500	\$2,000	\$2,100	\$2,200	\$2,250	\$2,300
3PL 1	0.23	0.12	60	180	240	252	264	270	276
3PL 2	0.87	0.45	225	675	900	945	990	1,012.5	1,035
3PL 3	0.19	0.11	55	165	220	231	242	247.5	253
3PL 4	0.36	0.18	90	270	360	378	396	405	414
Retailer	0.28	0.14	70	210	280	308	308	315	322

Table 7: Large Case: Bonus Sharing Between RSC Entities (in \$1,000)

	N	N^{nor}_{3PL}	\$50,000	\$60,000	\$65,000	\$70,000	\$75,000	\$80,000
3PL 1	0.284	0.205	10,227.854	12,273.425	13,296.210	14,318.995	15,341.781	16,364.566
3PL 2	0.179	0.128	6,422.977	7,707.573	8,349.870	8,992.168	9,634.466	10,276.763
3PL 3	0.115	0.0830	4,147.280	4,976.736	5,391.464	5,806.192	6,220.912	6,635.648
3PL 4	0.412	0.296	14,816.722	17,780.067	19,261.739	20,743.411	22,225.083	23,706.755
Retailer	0.400	0.288	14,385.167	17,262.201	18,700.717	20,139.234	21,577.751	23,016.267

For the large case (table 7), it can be seen that any amount of the bonus would be beneficial for the 3PLs. However, the retailer's effort would be rewarded in the case the producer pays at least $65,000 thousands as a bonus. In this case, the producer would not only avoid paying penalties, but also could save around $30,952 thousands of the money that she used to pay to government. From the results, we can see that if partners agree on better coordinating their activities, more products could be collected. The latter would lead to a green supply chain for the producer while the investment of other supply chain entities would be rewarded.

5. Conclusion

The pharmaceutical industry has developed at a very fast rate in the last decades, facing a rapidly growing market. However, environmental and governmental changes pressurize the companies to step ahead and change their practices. The recovery process and reverse supply chains of unsold or unwanted medications become an essential asset for this industry. A wide range of proactive actions could be implemented in the supply chain for reducing or minimizing the amount of pharmaceutical wastes left in the environment.

The pharmaceutical supply chain is a complex decision-making system at the tactical level. In general, it includes many actions, such as placement of waste materials recycling, long-term RSC chain coordination contract drafting, recovery channels of reverse logistics, and recovery efforts designing [4, 5]. Since pharmaceutical RSC activities fall outside core functions of a company, the majority of the activities are handled through third-party logistics providers (3PL) [6]. Hence, the reverse supply chain is not usual to be managed by one company. To optimize the network efficiency, effective coordination mechanism is necessary.

This paper has addressed the coordination method in a RSC of a real pharmaceutical case study. Inspired by Walther et al. [31], we developed a negotiation-based mechanism by the aid of a linear mathematical model that re-

flects the relationship between the retailer (producer representative) and several 3rd party logistics companies. The model was decentralized and a sub-model for each 3PL company was extracted. In order to solve the sub-models, the Lagrangian relaxation method was used. Numerical results for a small and a large case study were obtained and discussed. Finally, a bonus was shared between the RSC entities based on their contribution to the supply chain. Results show that coordination could ensure the complete collection of all unsold medications at customer zones. As a result, the producer would not pay penalties and she will be in a good reputation in the market. At the same time, the proposed coordination approaches leads to a win-win situation for the reverse supply chain entities, where each effort is rewarded. It is worth mentioning that implementing this way of coordination is not straight forward. RSC coordination is still a new reality for many of the network entities who are change reluctant.

Further research is necessary to involve customers (3rd echelon) of the network in the coordination model and introduce some incentives for their coordination efforts. Considering a multi-period tactical planning model could also be investigated. Finally, a thorough examination of how this new planning approach could be implemented would be relevant.

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Table A1: Large Case: Collecting Fees ($/kg) for 1 kg of a Product

Product	Customer	Collecting Fees	Current Prices	3PL 1	3PL 2	3PL 3	3PL 4
1	1	0.66	0.45	540.00	540.00	540.00	540.00
1	2	1.05	0.45	1,080.00	1,080.00	1,080.00	1,080.00
1	3	0.55	0.45	810.00	810.00	810.00	810.00
1	4	0.55	0.45	270.00	270.00	270.00	270.00
2	1	0.07	0.03	86.25	86.25	86.25	86.25
2	2	0.00	0.03	86.25	86.25	86.25	86.25
2	3	0.00	0.03	517.50	517.50	517.50	517.50
2	4	0.02	0.03	172.50	172.50	172.50	172.50
3	1	0.48	0.75	192.00	0.00	192.00	0.00
3	2	1.11	0.75	498.97	0.00	397.03	0.00
3	3	0.32	0.75	192.00	0.00	64.00	0.00
3	4	1.26	0.75	502.43	0.00	502.43	19.14
4	1	0.00	0.02	93.75	93.75	93.75	93.75
4	2	0.00	0.02	93.75	93.75	93.75	93.75
4	3	0.00	0.02	112.50	112.50	112.50	112.50
4	4	0.00	0.02	75.00	75.00	75.00	75.00

Table A1: Large Case: Collecting Fees ($/kg) for 1 kg of a Product

Product	Customer	Collecting Fees	Current Prices	3PL 1	3PL 2	3PL 3	3PL 4
5	1	0.32	0.45	70.25	70.25	70.25	70.25
5	2	0.49	0.45	158.06	0.00	158.06	105.38
5	3	0.63	0.45	181.79	57.92	181.79	140.50
5	4	0.17	0.45	52.69	0.00	52.69	35.13
6	1	0.45	0.35	138.30	0.00	138.30	92.20
6	2	0.11	0.35	34.58	0.00	34.58	23.05
6	3	0.40	0.35	94.08	0.00	147.94	80.68
6	4	0.17	0.35	79.36	0.00	0.00	34.58
7	1	0.18	0.15	59.40	0.00	59.40	39.60
7	2	0.28	0.15	89.10	0.00	89.10	59.40
7	3	0.23	0.15	74.25	0.00	74.25	49.50
7	4	0.23	0.15	74.25	0.00	74.25	49.50
8	1	0.03	0.03	12.60	12.60	12.60	12.60
8	2	0.03	0.30	12.60	12.60	12.60	12.60
8	3	0.06	0.30	25.20	25.20	25.20	25.20
8	4	0.18	0.30	75.60	75.60	75.60	75.60

Table A1: Large Case: Collecting Fees ($/kg) for 1 kg of a Product

Product	Customer	Collecting Fees	Current Prices	3PL 1	3PL 2	3PL 3	3PL 4
9	1	0.08	0.20	16.88	16.88	16.88	16.88
9	2	0.21	0.20	45.00	45.00	45.00	45.00
9	3	0.13	0.20	28.13	28.13	28.13	28.13
9	4	0.11	0.20	22.50	22.50	22.50	22.50
10	1	0.02	0.03	22.68	22.68	22.68	22.68
10	2	0.02	0.03	19.32	19.32	19.32	19.32
10	3	0.02	0.03	21.84	21.84	21.84	21.84
10	4	0.02	0.03	20.16	20.16	20.16	20.16
11	1	0.01	0.01	7.35	7.35	7.35	7.35
11	2	0.02	0.01	18.38	18.38	18.38	18.38
11	3	0.03	0.01	29.40	29.40	29.40	29.40
11	4	0.02	0.01	18.38	18.38	18.38	18.38
12	1	0.00	0.01	12.75	12.75	12.75	12.75
12	2	0.00	0.01	25.50	25.50	25.50	25.50
12	3	0.00	0.01	6.38	6.38	6.38	6.38
12	4	0.00	0.01	19.13	19.13	19.13	19.13

Table A1: Large Case: Collecting Fees ($/kg) for 1 kg of a Product

Product	Customer	Collecting Fees	Current Prices	3PL 1	3PL 2	3PL 3	3PL 4
13	1	0.00	0.02	5.90	5.90	5.90	5.90
13	2	0.00	0.02	8.85	8.85	8.85	8.85
13	3	0.00	0.02	23.60	23.60	23.60	23.60
13	4	0.00	0.02	20.65	20.65	20.65	20.65
14	1	0.11	0.05	22.50	22.50	22.50	22.50
14	2	0.03	0.05	5.63	5.63	5.63	5.63
14	3	0.02	0.05	3.75	3.75	3.75	3.75
14	4	0.03	0.05	5.63	5.63	5.63	5.63
15	1	0.03	0.03	6.60	6.60	6.60	6.60
15	2	0.05	0.03	9.90	9.90	9.90	9.90
15	3	0.04	0.03	8.25	8.25	8.25	8.25
15	4	0.04	0.03	8.25	8.25	8.25	8.25
16	1	0.03	0.01	19.50	0.00	19.50	13.00
16	2	0.02	0.01	15.17	0.00	15.17	15.17
16	3	0.01	0.01	6.50	0.00	6.50	6.50
16	4	0.01	0.01	4.33	0.00	4.33	4.33

Table A1: Large Case: Collecting Fees ($/kg) for 1 kg of a Product

Product	Customer	Collecting Fees	Current Prices	3PL 1	3PL 2	3PL 3	3PL 4
17	1	0.00	0.02	1.05	1.05	1.05	1.05
17	2	0.00	0.02	2.10	2.10	2.10	2.10
17	3	0.00	0.02	3.15	3.15	3.15	3.15
17	4	0.00	0.02	4.20	4.20	4.20	4.20
18	1	0.00	0.15	2.00	2.00	2.00	2.00
18	2	0.00	0.15	3.00	3.00	3.00	3.00
18	3	0.00	0.15	2.50	2.50	2.50	2.50
18	4	0.00	0.15	2.00	2.00	2.00	2.00
19	1	0.00	0.01	2.50	2.50	2.50	2.50
19	2	0.00	0.01	0.50	0.50	0.50	0.50
19	3	0.00	0.01	3.75	3.75	3.75	3.75
19	4	0.00	0.01	1.25	1.25	1.25	1.25
20	1	0.00	0.01	1.20	1.20	1.20	1.20
20	2	0.00	0.01	2.80	2.80	2.80	2.80
20	3	0.00	0.01	0.80	0.80	0.80	0.80
20	4	0.00	0.01	3.20	3.20	3.20	3.20